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NAVAL CONSTRUCTION BATTALION CENTER
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The performance of the porous friction surfacing (PFS) on a runway at the U.S. Naval Air Station, Dallas, Texas, was evaluated. Runway friction measurements with a mu-meter, field permeability measurements, visual condition surveys, corings of the pavement for determination of asphalt binder properties, and an investigation of aircraft accidents attributed to hydroplaning were accomplished. The results of these investigations show that the porous friction surface is providing (1) a highly skid-resistant surface for high-speed jet

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aircraft operations; (2) an excellent surface with few visible defects; and (3) a minimum service life of 5 years with a potentially much longer life.

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INTRODUCTION

The first use of a porous friction surfacing (PFS) on a military runway in North America was at the U.S. Naval Air Station (NAS), Dallas, Texas, where PFS was laid down over a portion of Runway 17-35 in September 1971. This installation provided a unique opportunity to monitor the performance of PFS under high-tire-pressure, high-load, jet aircraft traffic. The Civil Engineering Laboratory (CEL) was tasked by the Naval Facilities Engineering Command to begin a 2-year monitoring program in July 1974.

The performance of the porous friction surface at NAS Dallas was monitored through these techniques:

(1) Measuring runway friction with a Mu-Meter friction-measuring device
(2) Making field permeability tests with a CEL-developed falling head permeameter
(3) Visually surveying the condition of the PFS using the statistically based procedure developed by CEL
(4) Coring the pavement and determining asphalt binder properties and PFS density
(5) Investigating any aircraft accidents attributed to skidding or hydroplaning

The initial plans called for four visits to the station at 6-month intervals beginning in August 1974. The first and third visits were to consist of skid testing, permeability testing, coring of the pavement, and visual condition survey. The second and fourth visits were to conduct visual condition surveys only.

STATION BACKGROUND

Naval Air Station, Dallas is located midway between Fort Worth and Dallas near the town of Grand Prairie, Texas. The primary mission of the station is to support Naval and Marine Air Reserve training and to provide a base for a unit of the Texas Air National Guard. The station also provides airfield facilities for the Ling-Temco-Vought Corporation plant located on the west side of the station. An aerial photograph of the station is shown in Figure 1.

The primary aircraft using the station since construction of the PFS runway have been F8, F4, A7, and KC-97. Most other aircraft in the military inventory have used NAS Dallas on a transient basis. Load and tire pressure data for the primary aircraft are given in Table 1.

Flight operations at NAS Dallas have averaged approximately 9,000 per month during the period 1971 to 1976. Almost all aircraft operations were on Runway 17-35, with occasional light aircraft and helicopters using Runway 13-31.

A summary of climatological data over a 21-year period is given in Appendix A.

FIELD VISITS

NAS Dallas was first visited by the CEL team on 26 to 28 August 1974. During this visit, runway friction measurements were made with a Mu-Meter friction-measuring device loaned to CEL by the Federal Aviation Administration (FAA), Southwest Region. Permeability tests, a visual condition survey, and arrangements for pavement coring also were completed during this visit.

During the second visit, 6 to 8 January 1975, runway friction measurements with the FAA Mu-Meter and a visual condition survey were accomplished. Pavement cores, which had been cut after the first visit, were taken to CEL for laboratory testing.

During the third visit, 18 to 19 November 1975, runway friction measurements, permeability tests, a visual condition survey, and arrangements for pavement coring were made.

The fourth and final visit was made on 29 June 1976, when a visual condition survey and permeability tests were made. Runway friction measurements were not made as the FAA Mu-Meter was not available.

FIELD TEST PROCEDURES

Runway Friction Measurements

The skid resistance/hydroplaning characteristics of the PFS were evaluated with a Mu-Meter friction-measuring device (Figure 2). The Mu-Meter is a small trailer, designed and manufactured by M. L. Aviation of Maidenhead, England. It measures the side-force friction coefficient generated between the pavement surface and the pneumatic tires on the two wheels that are set at a fixed toe-out (yaw angle) to the line of travel. The Mu-Meter is a continuous recording device that graphically records the coefficient of friction, mu*, versus the distance traveled along the pavement.

*The symbol mu or μ designates the coefficient of friction, which is a constant used to represent the ratio of frictional force to force normal to the pavement surface.

Water was applied to each test section with a water truck provided by the station. The water truck was calibrated to apply 0.1 inch of water on the skid test strip with each pass.

Test sections were selected to determine the effect of aircraft traffic on the performance of the PFS. Two sections, designated traffic and nontraffic areas, are shown in Figure 3. The previously calibrated water truck made two passes over each test strip. Mu-Meter runs at 40 miles per hour, which is 1.2 times the theoretical hydroplaning speed for this vehicle, were initiated immediately after completion of the second water truck pass. The runs were made in alternate directions at convenient time intervals until a dry pavement condition was reached or 30 minutes had elapsed. All water truck and Mu-Meter operations were measured to the nearest second with a stopwatch.

Permeability Tests

The device and technique used for the permeability tests were designed by Tomita and are described in Reference 2 as follows:

"The drainage meter for the falling-head permeability measurements was devised to be simple field test equipment. A piece of hard rubber 1/4 inch by 1/4 inch was cemented to the bottom face of a 4-inch-diameter Lucite tube. A bead of polyethylene film sealer was placed on the bottom face of the rubber. During field use, an arrangement of clamps and a wooden platform on the outside of the tube supported weights that forced the lower edge of the tube into watertight contact with the pavement. Four 10-pound weights were placed on the platform, and the tube was filled with water. A stopwatch was started when the water level was at 42 inches above the pavement surface, and time durations for the water level to drop to 30-inch, 18-inch, and 6-inch levels were recorded. The four water levels above the pavement surface were marked on the Lucite tube.

The coefficient of permeability, k, under falling head may be determined by:

$$k = 2.3 \frac{a\,L}{A\,t} \left(\log_{10} \frac{h_o}{h_1} \right) \qquad (1)$$

where

a = area of the Lucite tube
A = area of the friction course through which water passes
L = length of the path water goes through
t = time
h_o = initial head or level of water
h_1 = final head of water

All terms in Equation 1 are easily measured or can be calculated for permeability test of laboratory-size specimens. However, for the drainage meter resting on a surface having infinite area, such as the friction

course layer, the term L is difficult to determine. The water must travel some unknown path down into the friction course beneath the tube and then out of the friction course beyond the periphery of the rubber footing and sealer. From observations of the experiments it appeared that most of the water flowed upward from the friction course in a spring-like manner after passing through the friction course beneath the rubber footing. The spring-like flow in plan view was in the shape of a ring 1 to 1 1/2 inches wide surrounding the tube.

Using a = 12.069 square inches, A = 9.823 square inches, average values of time, and an approximated value of L = 1.416 inches, the k values were determined by Equation 1 for various combinations of h_o and h_1.

Visual Condition Survey

The procedure used to make the visual survey of the PFS was the statistically based technique developed by CEL in 1968. Pavement defects are measured that permit the establishment of condition numbers (weighted defect densities). These numbers, which are direct indicators of the pavement condition, can be compared after each survey to determine quantitative changes in pavement defects.

TEST RESULTS

Friction Measurements

The pavement skid resistance results are reported in terms of coefficient of friction, μ (mu), as measured by the Mu-Meter. The actual friction coefficient versus distance traces recorded during the first test run are shown in Figures 4 through 6. The traces show the variation of friction coefficient within each test section. Appendix B contains all test results for each Mu-Meter run made by CEL at NAS, Dallas.

Figures 7 through 10 show changes in surface friction versus time after wetting for each pavement section tested. Figure 7 is plotted from data in Reference 1. These graphs demonstrate the natural drainage characteristics of the runway surface. The slopes of these curves show that the friction coefficient of the porous friction surface is not affected by time after application of water. This indicates the PFS is functioning as designed and is rapidly draining water from the pavement surface. For comparison, a typical plot of friction coefficient versus time after wetting for a conventional asphaltic concrete pavement is shown in Figure 11.

Friction coefficients at 3 minutes after water application obtained in all tests conducted* since 1971 were above 0.50. This coefficient is

*The Air Force Weapons Laboratory (AFWL) and CEL have conducted tests.

considered satisfactory, and no hydroplaning problems are expected. In addition, little variation of friction coefficient is noted within each test section. This desirable characteristic insures even braking by aircraft using the surface. Friction coefficients obtained in the traffic area were consistently lower than the nontraffic area. This difference is attributed to differences in pavement drainage due to construction variables. The difference in drainage is also evident in the permeability tests.

Pavement Cores

The results of laboratory tests on cores obtained in November 1974 and November 1975 are shown in Table 2. Table 2 also includes the results of tests on cores obtained in 1973 and reported on in Reference 2.

The penetration of the residual asphalt has been consistently low since the 1973 series of tests with the exception of the nontraffic area sample in 1973. It is assumed that this sample was contaminated in the extraction and distillation process, and the results are erroneous. The penetrations reached are typical of aging asphalts and have probably stabilized at their present levels.

Variations in bulk specific gravity are erratic, and no conclusive trend is discernible. The traffic area averages appear to show a densification. However, an analysis of variance between the samples indicates that the observed differences in sample specific gravities are due to sampling fluctuations and are not significant.

Permeability Tests

The results of the permeability tests using the previously described procedure are given in Table 3. Considerable variation was noted in tests performed within each area, and no definite trend developed. A marked difference in permeability between traffic and nontraffic areas has existed from the first tests in 1972. This difference is attributed to construction variations between individual paving lanes and possibly to some testing variables. Lower friction coefficients in the traffic area are believed to result from lower permeability in this area.

Visual Condition Survey

The results of the visual condition surveys by CEL and Southern Division, NAVFAC [3] are given in Tables 4 through 6. The total weighted defect density has increased from 0.10A (0.00A being no visible defects) in March 1972 to 0.22A in August 1974. No appreciable change was noted in January 1975 or June 1976. Based upon subjective visual examination, the condition of the PFS is excellent.

Accidents Attributed to Skidding

One aircraft accident has been attributed to skidding or hydroplaning since the porous friction surface was placed. An F8-H Crusader landed on 23 April 1973 and attempted to brake on a wet runway. The pilot reported no braking effect and, after blowing both tires, overran the runway. No injuries or aircraft damage resulted from the incident. NAS Dallas operations personnel reviewed their records and determined that the duty runway on 23 April 1973 was Runway 35. This means that the aircraft touched down on the porous friction surface heading north and probably did not begin braking until it was on the old slurry-sealed surface. This section of runway had an average friction coefficient of 0.16 (wet) in 1971 [4]. Friction coefficients of less than 0.40 establish a high potential for most aircraft to hydroplane; therefore, the low coefficient on the slurry seal probably started the F8-H hydroplaning.

Additional Observations

During most of the skid testing operations, water placed for skid testing purposes was observed running along the pavement surface rather than entering the PFS pores (Figure 12). This apparent lack of drainage did not reduce the friction coefficients to an unacceptable level. It is felt that tires rolling over this water develop sufficient pressure to force the water into the PFS pores and remove it from the surface.

Raveling of the PFS, which has been reported by others [3, 4], was observed by the CEL investigators. Most of the raveling apparently occurred during the first year after construction. Since that time only slight raveling along reflection cracks (Figure 13) and jet blast areas has been noted.

A fuel spill required patching of an area approximately 10 feet by 30 feet (Figure 14). Although the same mix used in paving the PFS was used for the patch, a very poor patching job resulted. The patch has raveled down to the underlying asphaltic concrete in several areas.

Operations personnel at NAS Dallas have reported occasional incidents of blown aircraft tires when pilots have braked too hard on the PFS. This problem generally occurred only with pilots who were not familiar with the PFS and the runway configuration at NAS Dallas. It is theorized that the pilots may have overreacted when approaching the lake at the south end of Runway 17-35 and locked their brakes on the PFS. Even in a wet condition the PFS has a high coefficient of friction, and the unsuspecting pilots' reactions may have been too slow to prevent a blowout.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study it can be concluded that the porous friction surface at NAS Dallas is providing:

(1) a highly skid-resistant surface for high-tire-pressure jet aircraft operations

(2) an excellent surface with few visible defects
(3) a minimum service life of 5 years with a potentially much longer life

It is recommended that pilots be informed of the very high frictional resistance of PFS and therefore, to expect excellent braking response. Additional investigation is needed to find better ways of patching PFS.

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3. Southern Division, Naval Facilities Engineering Command. Report: Airfield pavement condition survey at NAS Dallas. Charleston, S.C., Mar 1972.

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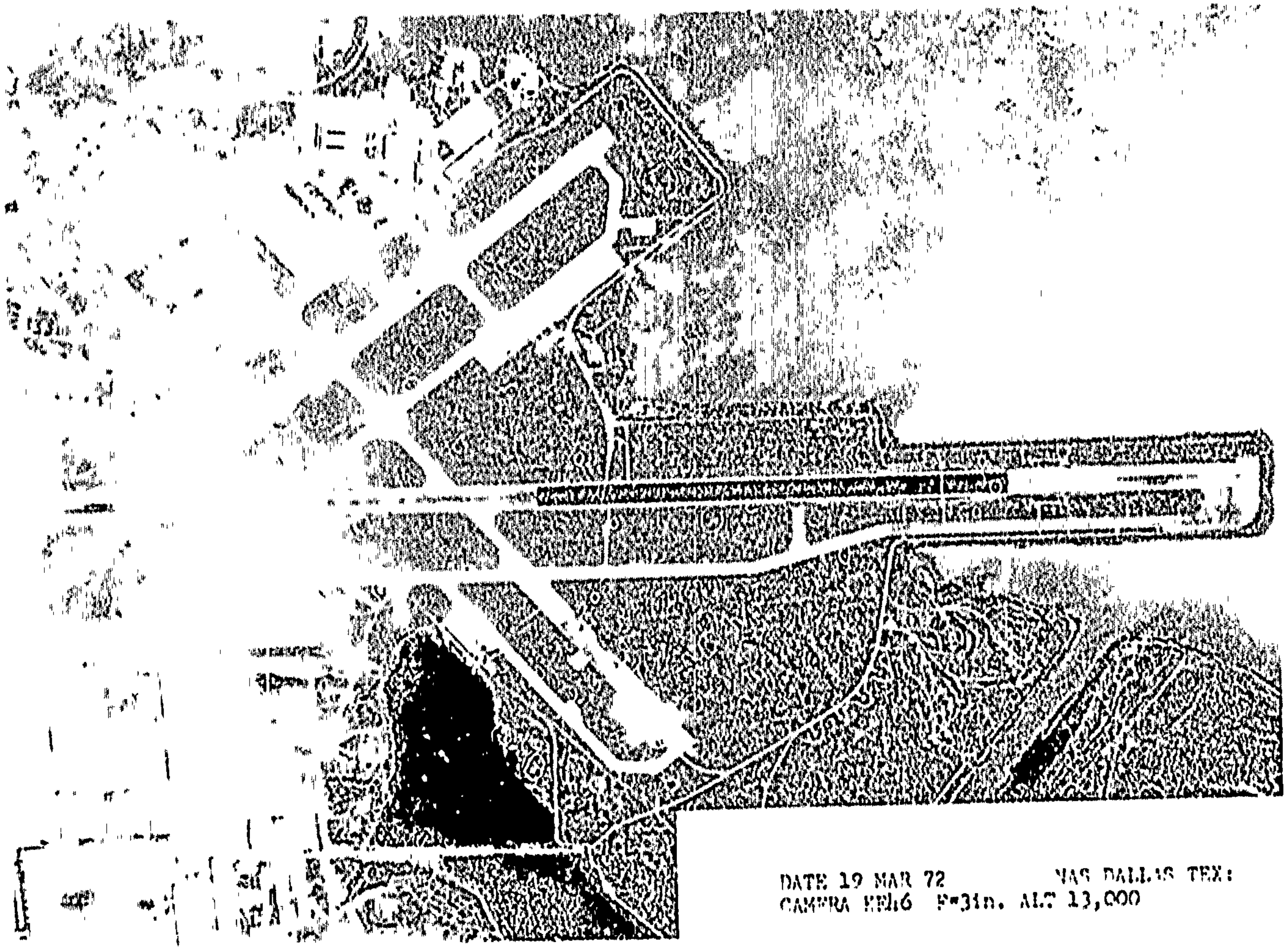


Figure 1. Aerial view of NAS Dallas, Texas.

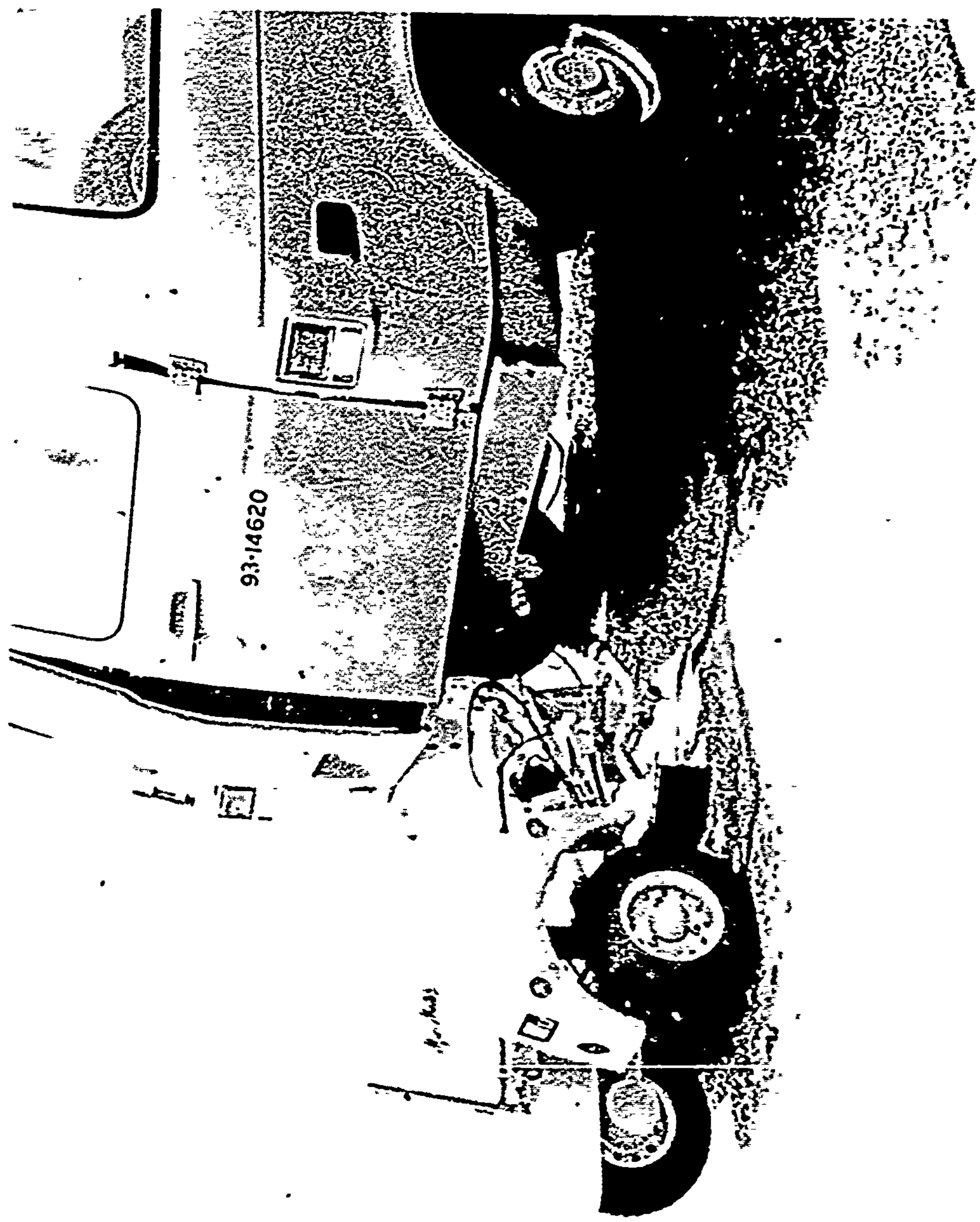


Figure 2. Mu-meter friction measuring trailer.

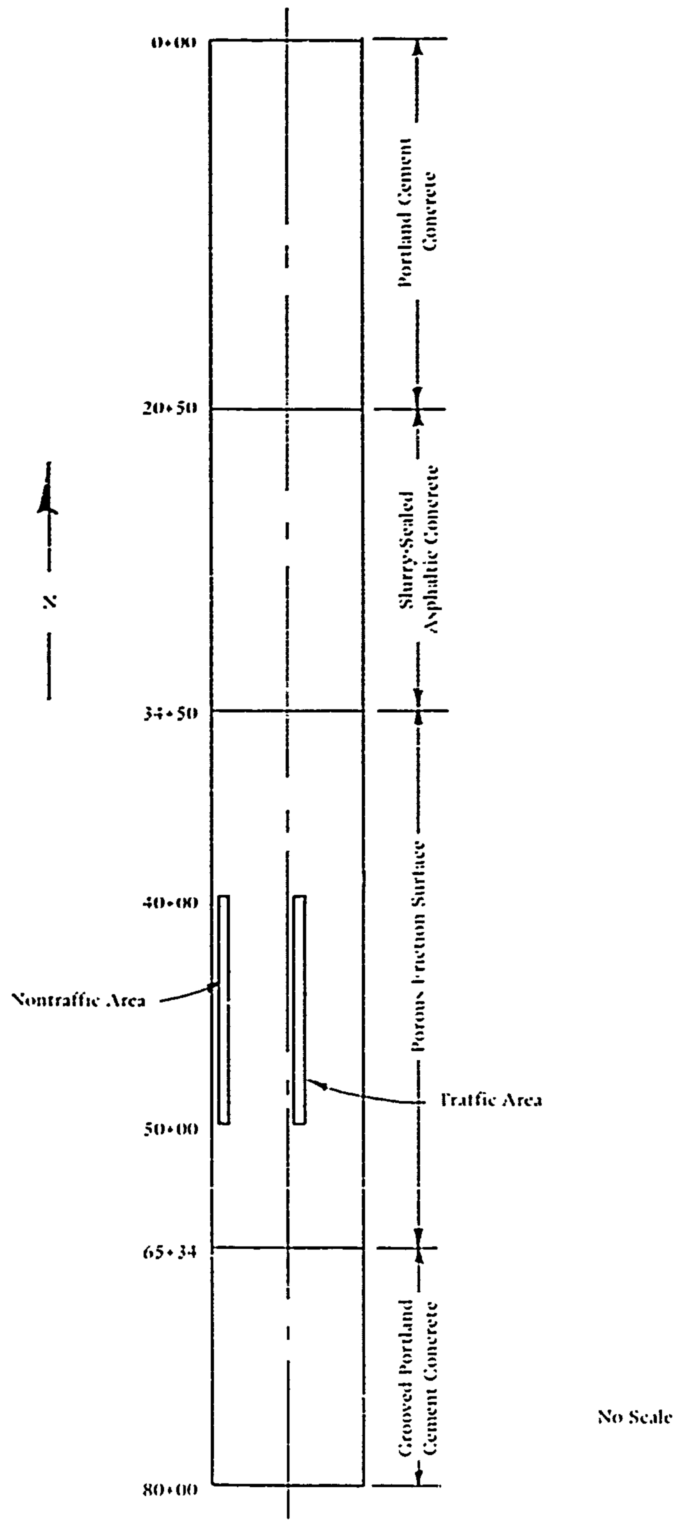
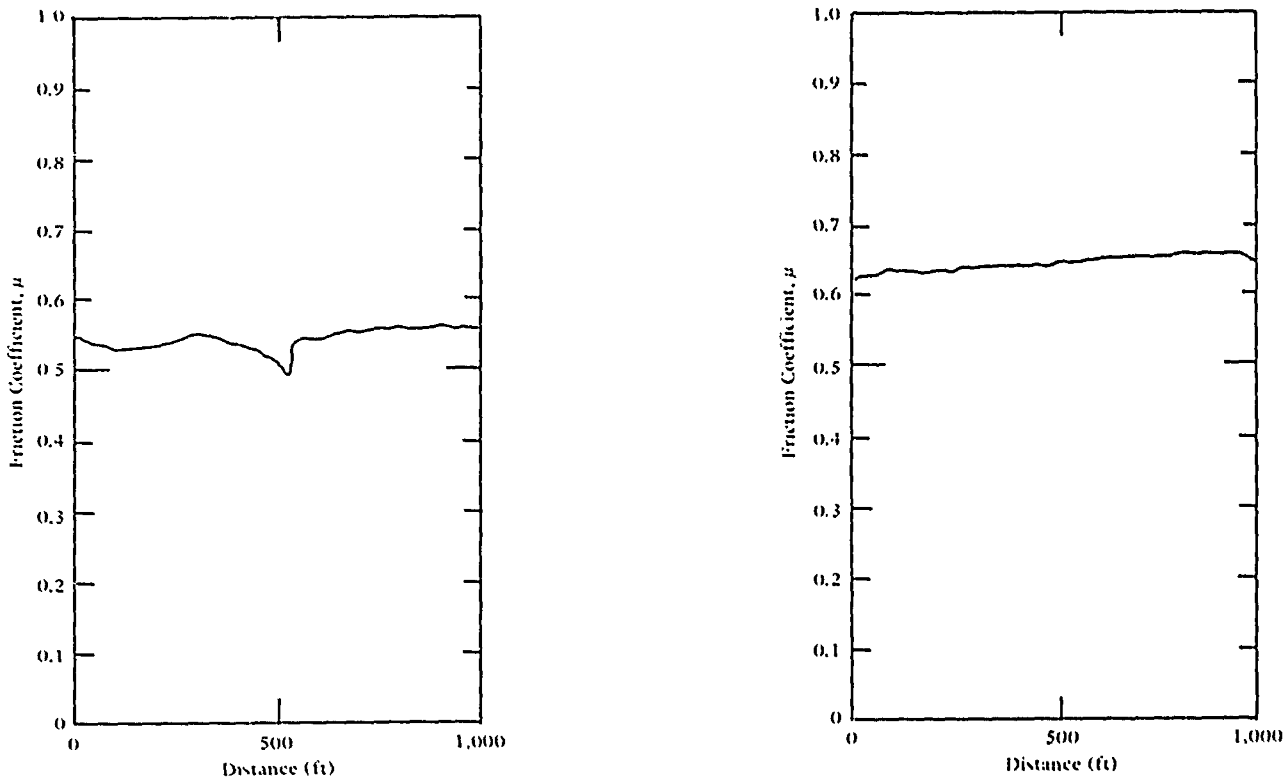


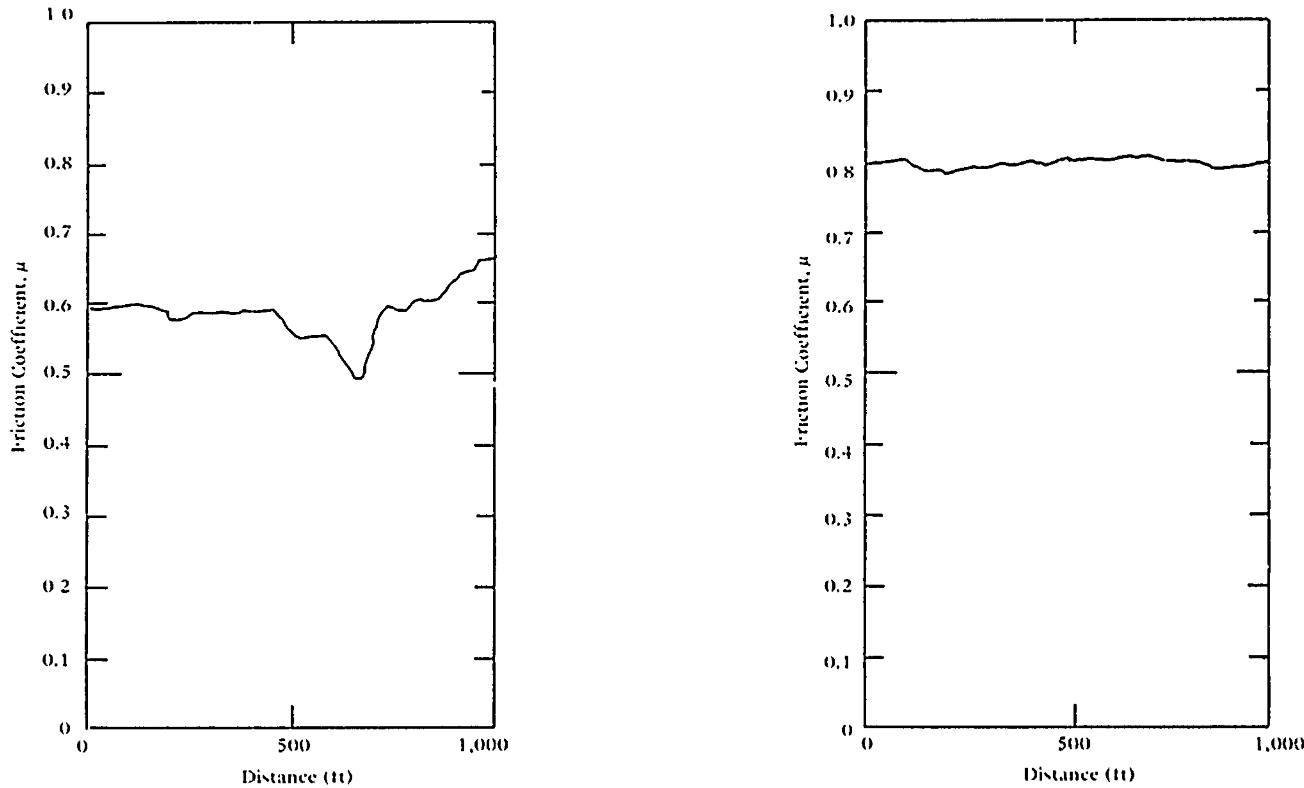
Figure 3. Test locations, runway 17-35, NAS Dallas, Texas.



(a) Traffic area.

(b) Nontraffic area.

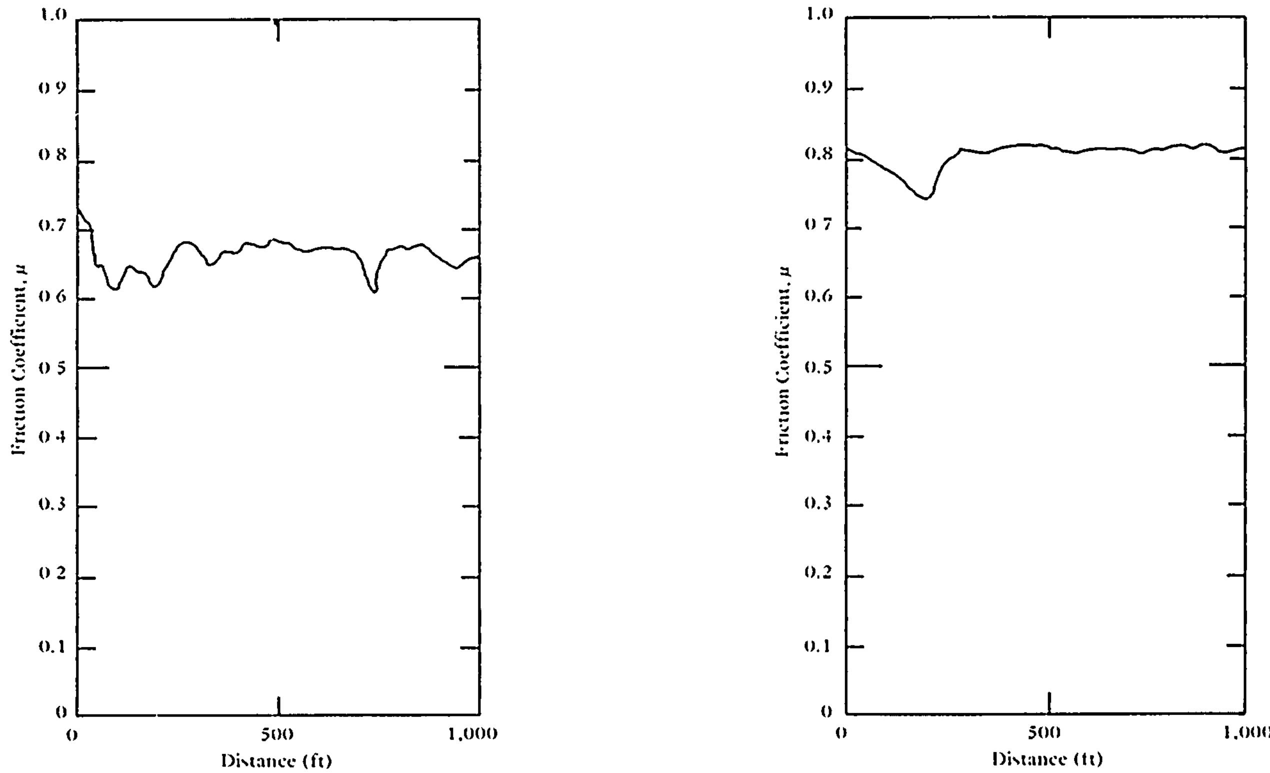
Figure 4. Mu-meter trace versus distance for porous friction surface at NAS Dallas on 27 August 1974.



(a) Traffic area.

(b) Nontraffic area.

Figure 5. Mu-meter trace versus distance for porous friction surface at NAS Dallas on 6 January 1975.



(a) Traffic area.

(b) Nontraffic area.

Figure 6. Mu-meter trace versus distance for porous friction surface at NAS Dallas on 17 November 1975.

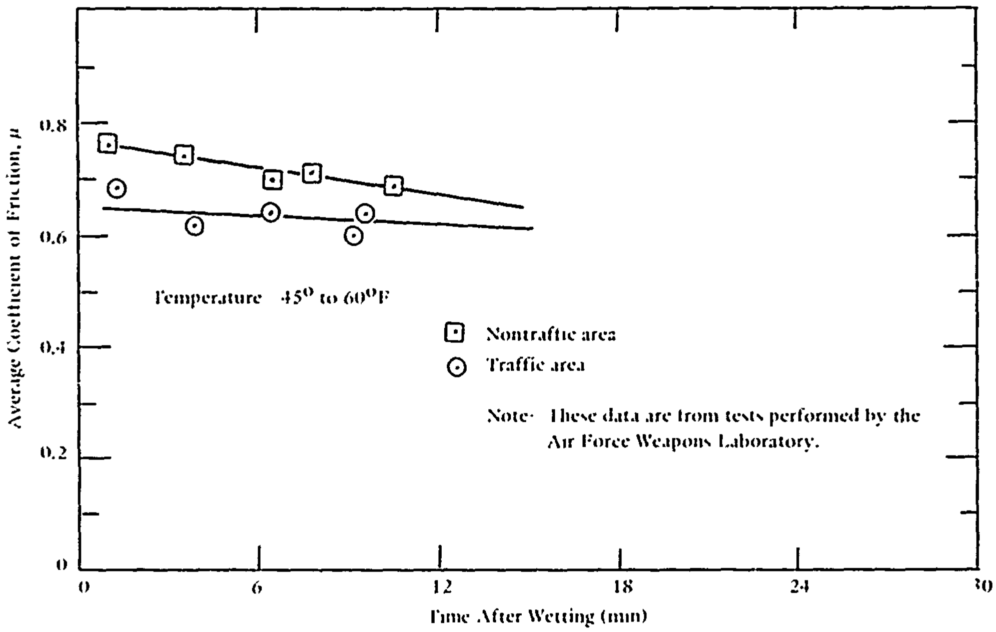


Figure 7. Mu-meter friction measurements for porous friction course at NAS Dallas in November 1971.

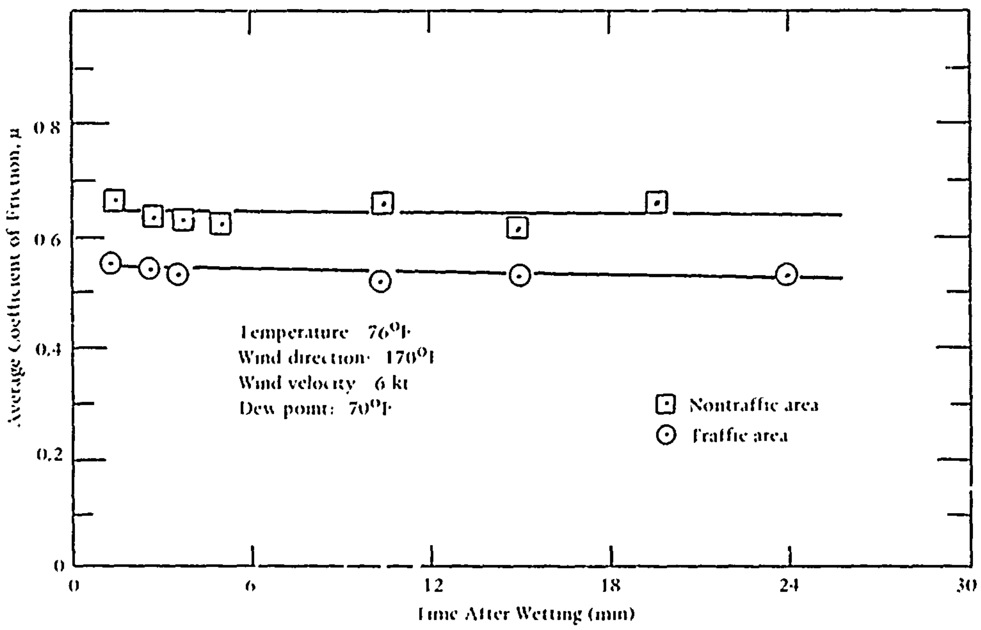


Figure 8. Mu-meter friction measurements for porous friction course at NAS Dallas in August 1974.

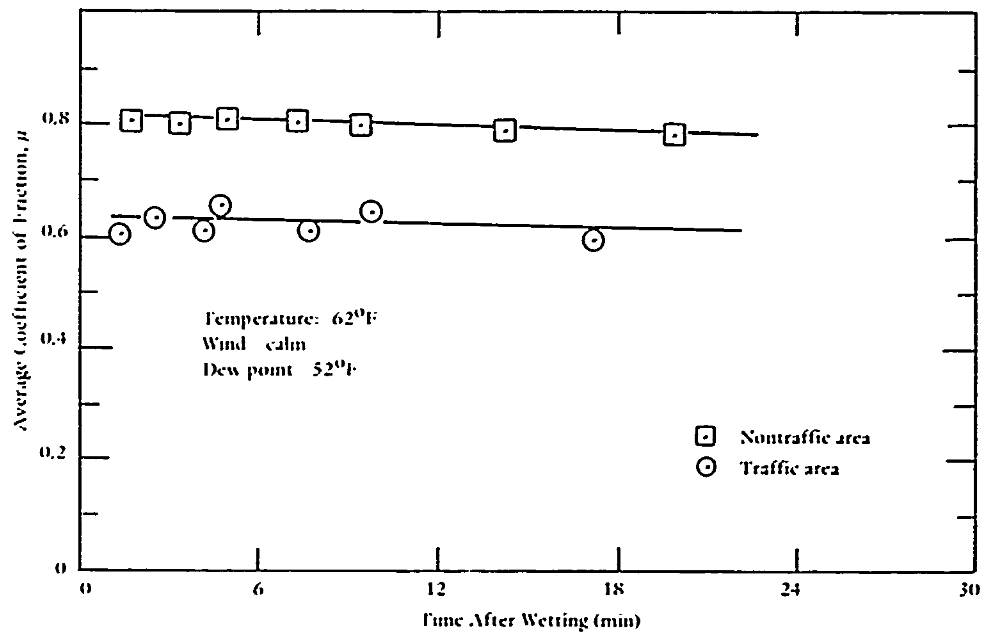


Figure 9. Mu-meter friction measurements for porous friction course at NAS Dallas in January 1975.

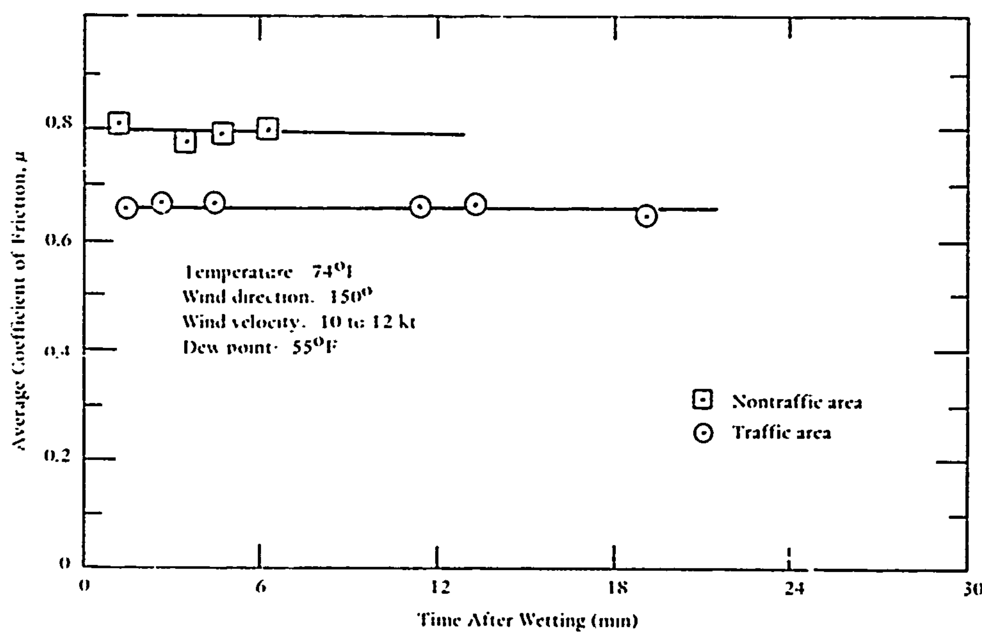


Figure 10. Mu-meter friction measurements for porous friction course at NAS Dallas in November 1975.

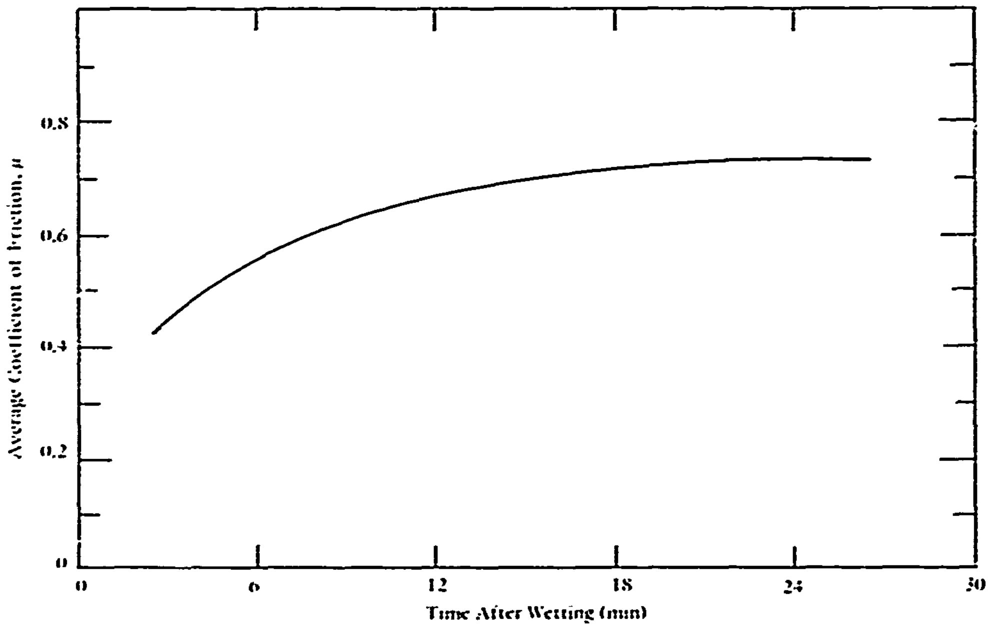


Figure 11. Typical mu-meter measurements on conventional asphaltic concrete.

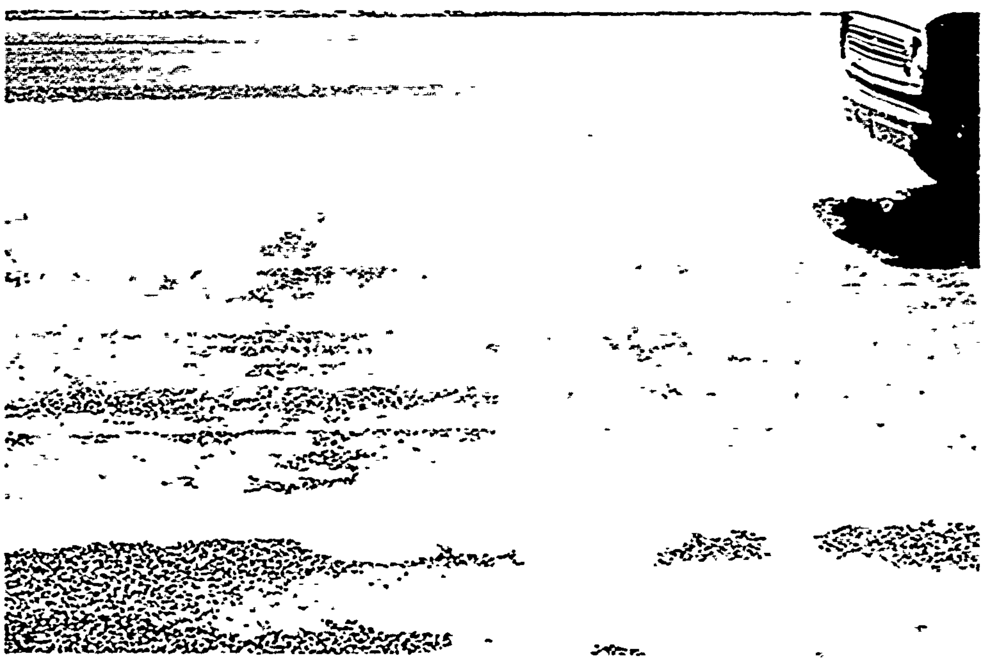


Figure 12. Water running on surface of porous friction surface.

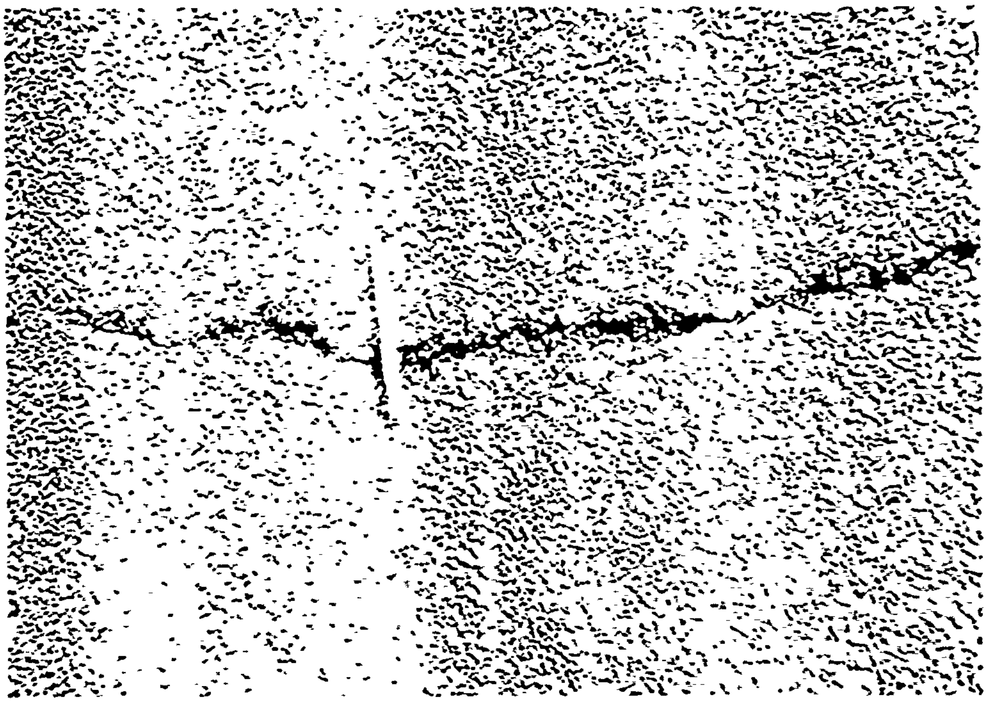


Figure 13. Reflection crack with slight raveling along edges.

Figure 14. Patched area in porous friction surface.

Table 1. Primary Aircraft Using NAS Dallas

Aircraft Type	Maximum Gross Weight of Aircraft (lb)	Tire Pressure of Main Landing Gear (psi)
A-7	42,000	265
F-4	54,600	250 to 400
F-8	29,500	300
KC-97	150,000	165
H-53	30,000	90

Table 2. Laboratory Test Results of Porous Friction Surface at NAS Dallas

Parameter	Specification	June 1973		November 1974		November 1975	
		Traffic Area	Nontraffic Area	Traffic Area	Nontraffic Area	Traffic Area	Nontraffic Area
Aggregate gradation, percent passing –							
1/2 in.	100	100	100	100	100	100	100
3/8 in.	90 to 100	100	100	100	100	100	100
No. 4	30 to 55	42.4	39.5	39.2	46.9	43.2	42.1
No. 10	0 to 22	14.2	3.9	10.7	14.3	13.2	13.9
No. 40	0 to 12	2.7	2.4	2.7	2.9	3.5	4.8
No. 100	-	1.3	1.2	1.4	1.4	1.9	3.1
No. 200	0 to 5	0.8	0.8	0.9	0.9	2.04	2.14
Bulk specific gravity	-	1.85	1.99	1.93	1.87	2.04	2.14
Asphalt content (%)	5.0 to 7.0	6.25	6.05	5.20	6.29	5.51	5.16
Asphalt penetration	45 to 60	14.8	66.0[a]	9.0	8.8	12.8	9.6

[a] Probable experimental error.

Table 3. Permeability Tests of Porous Friction Surface at NAS Dallas

Date of Test	Coefficient of Permeability (in./hr) for -	
	Traffic Area	Nontraffic Area
June 1972	268.0	482.0
August 1974	222.0	597.0
November 1975	122.9	511.4
June 1976	213.5	434.7

Table 4.

ASPHALTIC CONCRETE DISCRETE AREA DEFECT SUMMARY

Airfield NAS Dallas Facility Runway 17-35

Discrete Area Porous Friction Surface Area of Discrete Area (a) 308,400 ft^2

No of Sample Areas (b) 14 Ratio: (a/2500b) 8.81

Defect Type	Length or Area of Sampled Defects	Total Length or Area of All Defects (c) x Ratio	Defect Density (per 10 sq ft.) 10 d/a	Defect Severity Weight	Weighted Defect Density: (e) x (f)
	(c)	(d)	(e)	(f)	(g)
T.C., L.C. or LCJ*		267 ft	0.0009	3.5	0.03
Reflection Crack					
Faulting					
Patching		323 ft^2	0.010	4.0	0.04
Settlement or Depression					
Pattern Cracking					
Rutting					
Raveling		42 ft^2	0.001	7.0	0.01
Erosion–Jet Blast		51 ft^2	0.002	7.5	0.02
Oil Spillage		11 ft^2	0.0004	1.5	
Broken-up Area					
				Total	0.10A**

Remarks on Pavement Condition

Data Source: Reference 3.

* Transverse crack, longitudinal crack or longitudinal construction joint crack.

** Letter suffix "A" indicates asphaltic pavement.

Table 5.

ASPHALTIC CONCRETE DISCRETE AREA DEFECT SUMMARY

Airfield NAS Dallas Facility Runway 17-35

Discrete Area Porous Friction Surface Area of Discrete Area (a) 308,400 ft^2

No. of Sample Areas (b) 14 Ratio (a/2500b) 8.81

Date Surveyed - 28 August 1974

Defect Type	Length or Area of Sampled Defects	Total Length or Area of All Defects (c) x Ratio	Defect Density (per 10 sq ft) 10 d/a	Defect Severity Weight	Weighted Defect Density (e) x (f)
	(c)	(d)	(e)	(f)	(g)
T.C., L.C. or LCJ*	19 ft	167 ft	0.005	3.5	0.018
Reflection Crack	206 ft	1814 ft	0.059	2.0	0.118
Faulting					
Patching		428 ft^2	0.014	4.0	0.056
Settlement or Depression					
Pattern Cracking					
Rutting					
Raveling	8 ft^2	70 ft^2	0.002	7.0	0.014
Erosion Jet Blast		51 ft^2	0.002	7.5	0.015
Oil Spillage					
Broken-up Area					
				Total	0.22A**

Remarks on Pavement Condition

The reflection cracks run transversely across the runway and are approximately 1/8 to 1/4 in wide. Slight raveling was noted along the cracks.

* Transverse crack, longitudinal crack or longitudinal construction joint crack

** Letter suffix "A" indicates asphaltic pavement

Table 6.

ASPHALTIC CONCRETE DISCRETE AREA DEFECT SUMMARY

Airfield NAS Dallas Facility Runway 17-35

Discrete Area Porous Friction Surface Area of Discrete Area (a) 308,400 ft^2

No. of Sample Areas (b) 14 Ratio. (a/2500b) 8.81

Date Surveyed - 29 June 1976

Defect Type	Length or Area of Sampled Defects	Total Length or Area of All Defects (c) x Ratio	Defect Density (per 10 sq ft) 10 d/a	Defect Severity Weight	Weighted Defect Density: (e) x (f)
	(c)	(d)	(e)	(f)	(g)
T.C., L.C or LCJ*	24 ft	211 ft	0.007	3.5	0.024
Reflection Crack	210 ft	1850 ft	0.060	2.0	0.120
Faulting					
Patching		428 ft^2	0.014	4.0	0.056
Settlement or Depression					
Pattern Cracking					
Rutting					
Raveling	25 ft^2	220 ft^2	0.007	7.0	0.050
Erosion–Jet Blast		51 ft^2	0.002	7.5	0.012
Oil Spillage					
Broken-up Area					
				Total	0.26A**

Remarks on Pavement Condition

The pavement condition is virtually unchanged since the visual survey performed in August 1974.

* Transverse crack, longitudinal crack or longitudinal construction joint crack.

** Letter suffix "A" indicates asphaltic pavement

Appendix A

CLIMATOLOGICAL DATA FOR USNAS DALLAS

Table A-1. Mean Data

Month	Temperature Means (°F)			Precipitation Means (in.)		Wind	
	Daily Maximum	Daily Minimum	Monthly	Rain	Snow and Sleet	Mean Speed (kt)	Prevailing Direction
January	56.0	35.6	46.0	1.72	1.5	9.8	S
February	60.2	39.5	50.1	2.10	0.8	10.1	S
March	67.4	45.9	56.9	2.02	0.1	11.1	S
April	76.5	56.2	66.6	5.00	T	11.2	S
May	84.0	64.8	74.6	4.61	T	10.2	S
June	92.0	72.7	82.6	3.00	0.0	10.1	S
July	96.3	76.6	86.7	1.84	0.0	9.1	S
August	96.8	75.6	86.4	1.73	0.0	8.4	S
September	89.2	68.4	79.1	2.88	0.0	7.9	S
October	79.4	57.5	68.7	2.74	0.0	8.1	S
November	67.0	45.8	56.7	2.41	T	8.8	S
December	57.6	38.1	48.1	1.80	0.1	8.9	S
Annual	76.9	56.4	66.9	31.85	2.5	9.5	S

Table A-2. Extreme Data

Month	Temperature (°F)		Precipitation (in.)				
			Rain			Snow and Sleet	
	Record Highest	Record Lowest	Maximum Monthly	Minimum Monthly	Maximum in 24 Hours	Maximum Monthly	Maximum in 24 Hours
January	85	7	4.02	0.13	2.18	10.4	10.0
February	88	9	5.40	0.09	2.72	3.9	3.2
March	96	19	4.82	0.20	2.00	1.8	1.8
April	100	32	13.88	1.76	4.66	T	T
May	100	39	12.48	0.99	5.94	0.0	0.0
June	105	54	8.19	0.02	3.09	0.0	0.0
July	111	63	4.97	0.28	3.49	0.0	0.0
August	109	62	5.77	0.02	2.48	0.0	0.0
September	105	46	5.53	T	3.78	0.0	0.0
October	98	31	8.63	0.04	4.22	0.0	0.0
November	88	18	9.65	0.27	2.43	0.1	0.1
December	84	11	5.44	0.09	1.82	1.5	1.5

Appendix B

MU-METER TEST RESULTS FOR POROUS FRICTION SURFACE AT NAS DALLAS

Date	Test Location	Run No.	Average Time After Wetting (min)	Coefficient of Friction, μ		
				Average	Maximum	Minimum
27 August 1974	Traffic area	1	1.26	0.55	0.60	0.49
		2	2.43	0.54	0.56	0.53
		3	3.38	0.53	0.58	0.45
		4[a]	-	-	-	-
		5	10.52	0.52	0.55	0.50
		6	15.42	0.53	0.55	0.51
		7	24.02	0.53	0.59	0.50
		8	37.13	0.53	0.57	0.52
	Nontraffic area	1	1.60	0.65	0.66	0.64
		2	2.68	0.63	0.64	0.62
		3	3.68	0.63	0.66	0.63
		4	4.90	0.63	0.64	0.62
		5	10.47	0.65	0.66	0.64
		6	15.05	0.62	0.64	0.62
		7	19.55	0.65	0.67	0.64
6 January 1975	Traffic area	1	1.36	0.60	0.68	0.49
		2	2.51	0.64	0.66	0.57
		3	4.15	0.61	0.66	0.59
		4	4.85	0.66	0.68	0.56
		5	7.80	0.62	0.65	0.55
		6	9.91	0.65	0.68	0.64
		7	12.64	0.64	0.67	0.63
		8	17.34	0.61	0.62	0.58
	Nontraffic area	1	1.77	0.80	0.81	0.78
		2	3.26	0.81	0.83	0.76
		3	5.34	0.82	0.82	0.80
		4	7.31	0.81	0.83	0.77
		5	9.52	0.80	0.82	0.78
		6	14.17	0.79	0.80	0.76
		7	20.01	0.78	0.81	0.77

[a]No record.

continued

Appendix B. Continued

Date	Test Location	Run No.	Average Time After Wetting (min)	Coefficient of Friction, μ		
				Average	Maximum	Minimum
11 November 1975	Traffic area	1	1.47	0.66	0.75	0.60
		2	2.87	0.67	0.69	0.65
		3	4.39	0.67	0.69	0.55
		4	11.44	0.67	0.69	0.63
		5	13.22	0.67	0.68	0.62
		6	19.04	0.64	0.69	0.62
	Nontraffic area	1	1.02	0.81	0.82	0.74
		2	3.37	0.77	0.79	0.71
		3	4.76	0.78	0.79	0.74
		4	6.19	0.78	0.80	0.74

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